Appendix B

Denny Way/Lake Union CSO Project
Contract A

Technical Memorandum - S5

Denny Way CSO Solids Analysis

DRAFT

Prepared for
King County Department of Natural Resources

Prepared by
Black & Veatch

Contract No. E63002
April 1998

Table of Contents

List of Tables

List of Figures

1.0 Solids Analysis

This analysis is being performed at the request of King County to determine the impact of solids settling and removal on the operations and discharges from the Elliott West Facility. Data for this report has been developed in the Facilities Planning process and the 30% and 60% design process.

The following report includes a description of the system and tunnel operations; flows, velocities and storm events; solids and settling characteristics including scouring and sediment transport theory; flow characteristics; and probable solids dynamics.

2.0 Executive Summary

The Mercer Street Tunnel will receive flows during approximately 33 events during the average year. For 15 events per year, the flows will exceed the storage capacity of the Tunnel and some portion of the storm flow will be treated and discharged to Elliott Bay through the Elliott West Outfall. On a flow basis, 50% of the flow will be discharged to Elliott Bay.

The Tunnel will be filled during the beginning of a storm event. The 7.2 million gallons of storage will be used to collect the first flows from a storm event. During the one year storm event (Design storm 6) the Tunnel stores flows for greater than 40 hours, and the treated discharge occurs for approximately 7 hours. Pumping to the outfall only occurs when the Tunnel is already full. Flows into the system come from both east and west ends of the Tunnel. During Tunnel filling the Tunnel fills from both ends. Once the Tunnel is full, the flows from the east end continue through the Tunnel, and the flows from the west end only enter the wet well. Approximately 35-40 percent of the flow comes from the east end, with the balance from the west end.

Since the peak storm flows will occur when the Tunnel has already been filled, the velocities in the Tunnel are very low. The peak velocity in the Tunnel during the one year storm (Design Storm 6) is 0.94 feet per second. This peak flow velocity is not sufficient to scour or resuspend solids.

At these low velocities, solids will be removed from the flow in the Tunnel by settling. Depending on the flow velocity, the removal percentage can be determined using the settling curves from the Monitoring Report. At the peak velocity for the one year storm (Design Storm 6) 37 percent of the solids will be removed from the flows entering the Tunnel from the east. Only the flows through the Tunnel from the east would achieve solids removal in the Tunnel. No removal would be expected on the flows into the system from the west during pumping to the Outfall.

The Wetwell will be completely mixed, the system drain will almost always have scouring velocities, and the Tunnel will almost always have settling velocities, until it is drawn down as it is emptied. The solids will be removed in the Wetwell sump and in the Tunnel. This analysis indicates that there will be removal of solids in the Tunnel during storage and pumping events. These solids will be transferred to the Elliott Bay Interceptor (EBI). There will be less solids in the flows directed to the Elliott West Outfall and more solids transferred to West Point via the EBI.

3.0 Description of Tunnel and System Operation

The Mercer Street Tunnel consists of a 14 foot 8 inch diameter Tunnel that is 6200 feet long and has a slope of 0.0013 ft. per ft. The West Portal of the Tunnel is located at the Elliott West Facility, with an invert elevation of 75.0 (Metro Datum) and the East Portal is located at 8th Avenue and Roy Street with an invert elevation of 83.0. There is a cunette section in the bottom of the Tunnel.

The Tunnel will be utilized during storm conditions only. When water surface elevations rise to a point where they exceed established elevations at the Lake Union Tunnel, Central Trunk Diversion Structure, South Lake Union CSO Pipeline, the EBI Control Structure and the Denny Way Diversion Structure, flow will begin to be diverted from these structures into the Mercer Street Tunnel, for storage. After the storm, when capacity is available at West Point, the stored flows would be conveyed to the plant for treatment. Tunnel storage would be required during any storm that currently result in an overflow at the Denny Way Regulator Station.

When the Tunnel storage is full and the storm continues, the Elliott West Pumping station begins to operate, transferring flow to the Pump Discharge Channel. This flow is screened, disinfected, dechlorinated, and discharged to Elliott Bay through the Elliott West Outfall. Following a storm event, the Tunnel is drawn down by pumping the flows to the EBI.

Flow enters the Tunnel from two directions during filling and during the CSO treatment modes. The flow from the east side enters through the East Portal and consists of the flows from the Lake Union Tunnel, the Central Trunk, and the City of Seattle's South Lake Union CSO Pipeline. The flow from the west side enters through the Wetwell of the Elliott West Facility, and consists of flows from the EBI and from the Denny Way Diversion Structure (Denny Local and Denny Lake Union).

4.0 Flows, Velocities, and Storm Events

Table 1 shows the flows entering the Tunnel from each location during Design Storm 6 and the November 1978 storm. These flows are from the hydrographs in the *System Hydraulics* memo written by Brown and Caldwell.

Table 1

Peak Design Flows Entering Tunnel

Location	Flow in MGD	
	Design Storm 6	November 1978 (pumping)
South Lake Union CSO Pipeline (City)	33	65
Central Trunk Pipeline	14	52
Lake Union Tunnel Regulator	38	78
subtotal	85	195
Elliott Bay Interceptor Overflow to PS	49	103
Denny Local and Lake Union to PS	82	220
subtotal	131	323
total	216	518

Because these are peak flows, we would expect that the flows for each storm would increase from zero to the peak, and then decrease from the peak to zero. The hydrograph shapes for the inflows for these two storms are shown in the *System Hydraulics* memo. Other storms would have different peak flows. The peak flows for different areas for a given storm do not necessarily have peaks that occur at the same time. The flows given above were developed during the predesign process. The design flows are slightly different, as they include changes such as the 2020 design flows. The total east end one hour peak flow for the year 2020 Design Storm 6 is 103 MGD. This is the flow used for analysis of solids settling in this document.

The Tunnel will be filled before any pumping occurs. During Tunnel filling, the flows into the system will vary from zero to a higher flow. During some storms, the Tunnel will never completely fill, and no overflow will occur. Table 2 shows the currently estimated flow conditions based on actual flow data for years when rainfall exceeded the long term average rainfall value.

Table 2
Flow Conditions based on King County Modeling of Actual Rainfall Data
(long term averages)

Inflow to Tunnel/yr	559 Million Gallons
Number of Tunnel events	33
Treated Discharge to EW Outfall/yr	281 Million Gallons
Number of Treated discharge events	15
Untreated Discharge to Elliott Bay/yr	8 Million Gallons
Number of untreated discharge events	1

This means that on an average basis, 281 Million gallons will be discharged to Elliott Bay and 278 Million gallons will be sent to West Point for treatment per year. The discharge events will total 15 on an average basis. On a flow basis, 50 % of the flow goes to Elliott Bay. On a discharge basis, 55% of the events will not exceed the Tunnel storage volume.

The velocities in the Tunnel and the 84 inch system drain for Design storm 6 peak and one half of peak flows are shown in Table 3.

Table 3
Velocities in channels in feet per second

Location	Tunnel Full and pumping to Outfall	
	Peak Design Storm 6	1/2 Design Storm 6
Tunnel	0.94	0.47
84 inch system drain	3.4	1.7

5.0 Solids and Settling Characteristics

The following section describes the data available for solids in the Denny Way overflows, the theory and criteria for settling, and settling calculations for the Tunnel.

5.1 Monitoring Report

The quantity and characteristics of the suspended solids are described in the June 1997 *Monitoring Report*, prepared by Brown & Caldwell/Herrera Environmental Consultants. Items of interest in that report include the overflow characterization. Solids data included TSS (TSS), volatile suspended solids (VSS), and settleable solids concentrations (SS). Solids concentrations were highest from the EBI and lowest from the Denny Local. Minimal differences in solids concentrations were noted for samples collected from the Lake Union gate and the Lake Union weir, indicating that the wastewater is well-mixed in the Denny Lake Union Regulator. However, the sampling methodology did not allow for the determination of whether heavy particles may have been present in wastewater flowing along the bottom of the Regulator. The sampling could not be performed within several inches of the bottom due to the high velocities of wastewater through the discharge gate.

The majority of TSS detected in the overflow water samples were settleable solids as defined by the 1 hour settleable solids test using a 1-liter Imhoff cone. Sixty percent of the TSS were settleable in samples collected from the Lake Union gate, 60 percent for samples from the Lake Union weir, 57 percent for samples from the Denny Local gate, and 56 percent from samples from EBI. However, a comparison of mean TSS concentrations for the Lake Union gate before solids separation testing (90 mg/l) to after solids separation testing (55 mg/l) indicates that only 40 percent of the TSS settled out of the water. The lower percentage of settleable suspended solids calculated for solids separation testing is attributed to the greater settling distance in the columns than in an Imhoff cone.

Since the potential for long residence times in the Tunnel exists, the TSS was used to determine potential solids loading. This number is greater than the SS, and for the purposes of Tunnel cleaning will provide a more conservative design goal. The mean TSS concentrations noted in the monitoring report varied from 63.2 to 120.5 mg/l.

The *Monitoring Report* determined that the mean settling velocity for the sediment is 0.017 cm./sec. The settling curves indicated that the percent of TSS that settled during the tests ranged from 44 percent to 59 percent. The percentages are within the rages noted on other studies. The Median TSS settling velocity is 0.0042 cm./sec. This is near the lower end of the median ranges calculated for 17 CSO settling tests in North America by Pisano and Brombach. The geometric mean of 0.017 cm./sec was less than one tenth of the geometric mean (0.217 cm./sec) calculated for the 17 sites and similar to the geometric mean (0.011 cm./sec) calculated for seven stormwater settling tests in North America.

Results for the monitoring report indicate that between 41 to 56 percent of the TSS in the Denny Way Regulator Station overflow water have settling velocities of less than 0.025 cm./sec. Therefore, after 2 hours 13 minutes and 20 seconds of settling, approximately 50 percent of the suspended solids remained in the water. Volatile suspended solids data show that approximately 50 percent of the non-settled solids are composed of organic matter.

5.2 Sedimentation and Settling Design

Sedimentation is the separation from water, by gravity, of suspended particles that are heavier than water. The terms sedimentation and settling are used interchangeably. Four types of settling can occur: discrete particle, flocculent, zone and compression. More than one type of settling can occur at once. In this case, we expect both discrete particle and flocculent settling. In discrete particle settling, the particles settle as individual entities, and there is not significant interaction with neighboring particles. In flocculent settling, the particles coalesce or flocculate during the sedimentation operation. By coalescing, the particles increase in mass and settle at a faster rate.

For discrete particle settling, the mean settling velocity is used to calculate the necessary area of a basin required so that all particles will be removed. An overflow rate or surface loading rate is defined based on the settling velocity. (Vc = Q/A = overflow rate gal/ft day)

For continuous flow sedimentation, the length of the basin and the time a unit volume of water is in the basin (detention time) should be such that all particles with a given design velocity will settle to the bottom of the tank. (Vc = depth/detention time)

5.3 Department of Ecology Settling Criteria

Washington State Department of Ecology defines design criteria for primary settling of the following:

surface loading	800-1200 gpd/sf at average flow
	2000-3000 gpd/sf at peak hydraulic flow
depth	8-12 feet
detention time	1.5 to 2.5 hours

The Mercer Street Tunnel has a surface loading of 1140 gpd/sf at the Design Storm 6 peak flow, considerably less than the loading range allowed. The depth is 14.5 feet, in excess of the criteria, and the detention time is 1.6 hours at the Design Storm 6 peak flow. The Tunnel should exceed the performance of a primary clarifier.

The Wetwell has a surface loading of 173,611 gpd/sf at peak flow, a factor of approximately 100 above that which would be required for settling. The depth is 34 feet, greatly in excess of the criteria, and the detention time is just under 2 minutes. While the velocities are relatively low, the Wetwell will not function as a clarifier, and very little settling could be expected to occur.

5.4 Solids Percent Removal Calculations In Tunnel

The *Monitoring Report* by Herrera developed solids settling curves for the samples taken on Denny Way overflows. These settling curves were developed using methodology developed in Germany and described in Pisano and Brombach (1996). The solids were separated using a modified Imhoff settling column. The Solids settling curves were calculated using the methods described in Pisano and Brombach. The total suspended solids concentration in the settling column was calculated by mass balance. Then the mass of each settling fraction was added to the mass of total suspended solids measured in the non-settleable water collected after the settling test to five the total mass of suspended solids in the columns prior to the test. The percent of total suspended solids settling out at each settling velocity sampled was calculated by dividing each fractional mass by the total mass. The results of these tests are shown in Figure 5 of the Monitoring Report, included here in Figure 1.

This methodology gives a graph of total suspended solids removed versus velocity. To determine percent solids removal at a given settling velocity, the value can be read off the curve. No further calculations are required using these settling curves. The following describes the determination of the percentage of solids removal in the Mercer Street Tunnel, using these curves and comparing the local data to national data published in Pisano and Brombach (1996).

This removal rate is for flows entering the Tunnel from the east, during a full Tunnel condition. This rate is not the CSO Treatment Facility removal rate since flows from the west do not enter the Tunnel when the Tunnel is in the CSO treatment mode of operation. The system removal rates are less. Since the Tunnel is full, the time to transit the Tunnel can be calculated based on the flow. Given the time to transit the Tunnel, and the depth of the Tunnel in centimeters, (442 cm.) the settling velocity at a given flow can be calculated. Table 4 below shows these values for a range of flows.

Table 4
Settling velocities at various flows in the Tunnel
cm./sec

Flow in cfs		settling velocity available, from top of Tunnel
20		0.0086
60		0.0259
85		0.0367
100		0.0423
140		0.0604
158	Peak flow Design Storm 6	0.0667
195		0.0842
220		0.0950

Given these calculated settling velocities, the solids removal possible at those velocities can be determined using the settling curve methodology. The data available includes the Denny Way *Monitoring Report* prepared by Herrera Associates for Brown and Caldwell, and published data by Pisano and Brombach (1996). Table 5 shows the solids removal percentages for the range of settling velocities using both the local data and national data. Figure 1 shows the settling curves used to determine these removal percentages. This data indicates that at the one year storm peak flow of 158 cfs in the Tunnel, the settling velocity is 0.0667 cm/sec which should allow solids removal of 37 percent based on local data. The local data is within the expected ranges of the national data

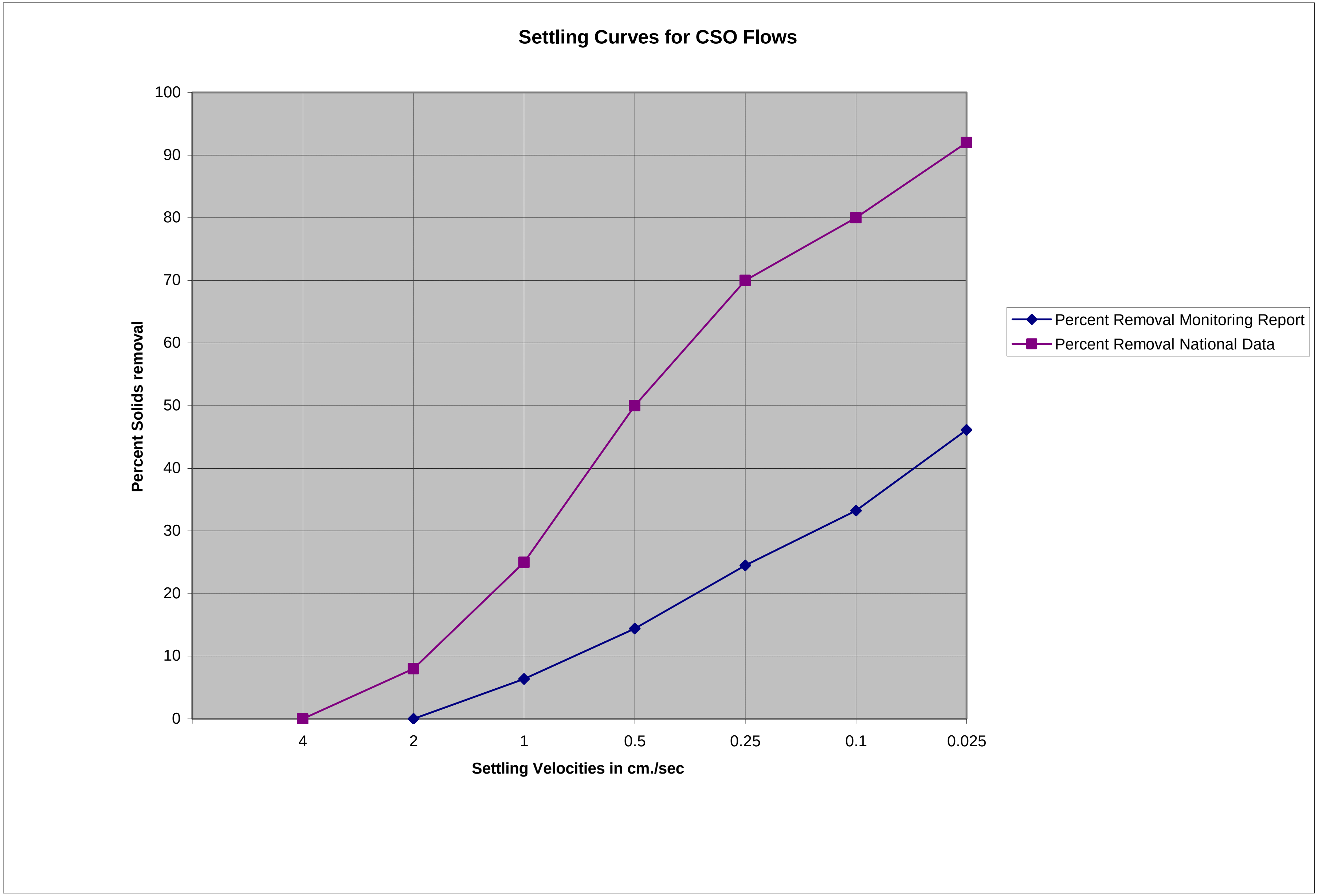
Figure 2 shows the solids removal percentages versus flow rate determined by the above method, for the monitoring report data and for data from Pisano and Brombach.

. Modeling of suspended solids removal should use 37 percent removal on the flows entering the Tunnel from the east during pumping to the Elliott West Outfall. This can be achieved at the peak flow period of the one year design storm.

Table 5
Tunnel Solids Removal percent vs. settling velocity

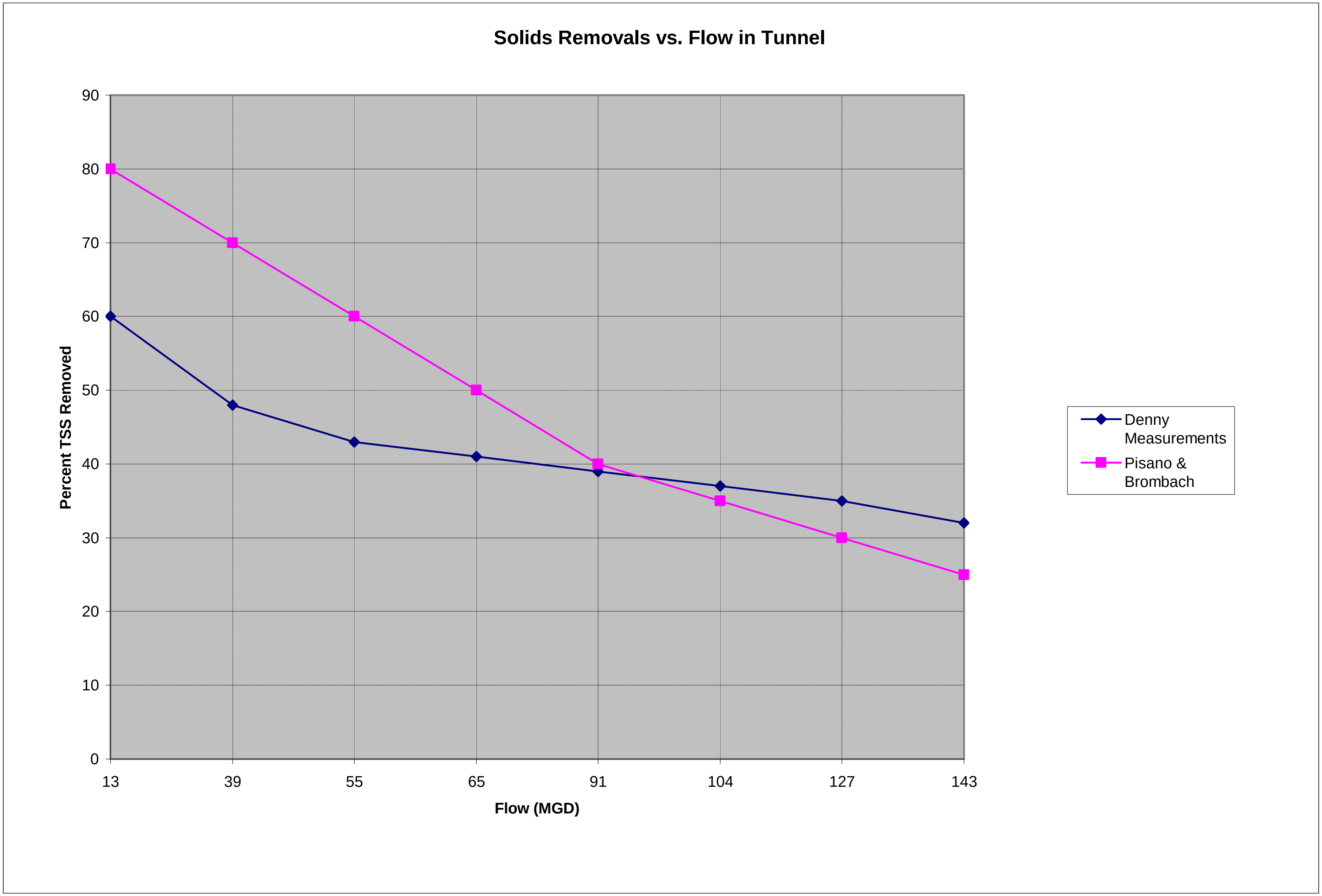
Q	Settling Velocity	Percent removal	
cfs	cm./s	Based on Monitoring Report figure 5 Hererra 1997)	Based on Pisano CSO data average Figure E Pisano and Brombach (1996))
20	0.0086	60	80
60	0.0259	48	70
85	0.0367	43	60
100	0.0432	41	50
140	0.0604	39	40
160	0.0691	37	35
195	0.0842	35	30
220	0.0950	32	25

Figure 1



Settling Curves for CSO Flows
100
90
80
70
60
50
40
30
20
10
0
Percent Solids removal
4
2
1
0.5
0.25
0.1
0.025
Settling Velocities in cm./sec
Percent Removal Monitoring Report
Percent Removal National Data

Figure 2


Solids Removals vs. Flow in Tunnel
Percent TSS Removed
0
10
20
30
40
50
60
70
80
90
13
39
55
65
91
104
127
143
Flow (MGD)
Denny Measurements
Pisano & Brombach

6.0 Scouring and Flow Characteristics

Technical Memorandum T3 described scouring theory and Tunnel cleaning methods. The following discussions include sections excerpted from this technical memo. Flow characteristics of the Tunnel, wet well and system drain are also discussed.

6.1 Scouring

Scouring is actually a form of solids or sediment transport. Solids are transported either by being rolled along the bottom of a channel or by being suspended in the fluid. Suspension in the fluid is a far more efficient means of transporting solids but, depending on the size and weight of the particles, can require higher flow velocities.

Rolling the sediment along the bottom requires that sufficient tractive force be applied to the particle to initiate motion. Assuming uniform flow, the tractive force is proportional to the component of the fluid weight parallel to the channel slope divided by the area of the channel. When other factors are held constant, increased channel depths and increased slope result in increased force applied on the particles. An increased velocity is implied by an increase in either of these two factors with other factors held constant.

Suspending a particle requires that the particle-settling velocity be exceeded in turbulent flow with upwellings. This velocity is higher than would be required to roll a particle along the bottom. The goal for efficient transport is to exceed the settling velocity of the particles to be moved.

There is a great deal of study in the area of sediment transport and a number of methods have been developed for determining sediment transfer rate. Some of the equations are based on sand flume research and some also consider actually-measured rates for rivers. In either case, the type of particles available for movement influences the development of the equations. The particles are generally assumed to be rock (higher specific gravity and more difficult to move). Use of these equations would tend to yield a more conservative design, as a significant fraction (around half) of the suspended solids (based on sampling for this project) are volatile and likely to have a specific gravity lower than rock (or larger diameter for a given particle weight).

6.2 Scouring Velocities

In the Tunnel flushing Technical Memorandum (T3) the sediment transport equations were reviewed. The minimum scouring velocities and shear stresses required for different Tunnel sections and slopes were calculated. To determine the minimum scouring velocities for sediment transport for both Tunnel alternatives, a spreadsheet was developed to look at possible Tunnel sections, the flow characteristics at increments of depth of 0.10 ft. and the amount of sediment carried at those depths. Three transport equations from Colby, Bagnold and Yang, as presented in Simons and Senturk (2), were used.

The answers provided by the equations diverged greatly (as is common with sediment transport equations). However, some general trends were noted in the Colby and Bagnold equations.

Transport is likely to be most effective at a depth that fully covers the shelves adjacent to the cunette with flow at an acceptable velocity. Transport is less effective if flow extends toward the top of the Tunnel because the velocity will be decreased in accordance with circular pipe section properties. Scouring will occur during periods when the Tunnel is less than full, not when the Tunnel is full.

The minimum desirable velocity is between 2 and 3 feet per second (preferably closer to 3 feet per second to move grit). The depths and flows associated with a velocity of 3 fps are shown in Table 6. The steeper the Tunnel, the less water needed to achieve cleaning velocities.

Table 6
Depth and Flow for 3 fps Cleaning Velocity at Alternative Slopes

Slope (ft./ft.)	Depth of flow (ft.)	Flow (mgd)	Cunette Flow Condition
0.00164	1.5	4.2	Cunette full
0.00164	2.1	15.5	Flow across Tunnel width
0.0008	1.5	6.0	Cunette full (velocity is only 2.67 fps)
0.0008	2.4	24.0	Flow across Tunnel width

There is a publication available from the EPA (Pisano) that covers deposition and flushing, specifically in smaller conveyance pipes. The author has continued his research and later papers are available. However, this publication summarizes and references a number of other papers. Two publications are referenced (Sonnen and Yao) that cover sediment transport. Specifically, Yao provides design shear stresses for self-cleaning. These are 0.02 to 0.04 psf for particles 0.2 to 1.0 mm in size with a shear stress of 0.06 to 0.08 psf for larger particles. Pisano appears to equate the ability to carry a given sediment particle with its settling velocity in this publication.

The calculations for this factor are summarized in Table 7 which indicates the depth and flow rate at which the shear stress reached 0.06 psf.

Table 7
Depth and Flow for Shear Stress of 0.06 PSF

Slope (ft./ft.)	Depth of flow (ft.)	Flow (mgd)	Cunette Flow Condition (assuming cunette is in place)
0.00164	2.2	18.9	Flow across Tunnel width
0.0008	2.9	42.5	Flow across Tunnel width

Use of the same sediment transport equations for calculating settling that are used for studying the problem of Tunnel flushing would yield misleading results in some cases. Some equations are based on shear stress as a dominant factor in sediment transport. The shear stress equation assumes that there is uniform open channel flow with velocity limited by the friction force exerted by the walls and sediment. The assumption is that the force available to initiate sediment movement is proportional to the friction force and the component of fluid weight parallel to the channel slope.

However, flow through the filled Tunnel is not a uniform open channel situation. The friction force in the Tunnel is not setting the flow rate through the Tunnel. The downstream conditions (pumping rate) are settling the flow rate through the Tunnel. Actual friction losses in the Tunnel in this situation will be quite low because the velocities in the Tunnel are quite low. Hence the available force for sediment transport is low. This means that the sediment transport equations based on the shear stress should be abandoned in favor of those based on the fluid velocity. For instance, the Yang method, which is heavily dependent on the assumed shear stress predicts a sediment flow of 578 lb/sec at 85 cfs and 836 lb/sec at 195 cfs. The Bagnold method, which uses the channel slope (and effectively the shear stress) in addition to the velocity predicts 9.5 lb/sec at 85 cfs and 50 lb/sec at 195 cfs. The Colby method, which is based on velocity and empirical data predicts no sediment transport at these low velocities.

In general, the less tied to invalid open channel assumptions a sediment transport model is, the less carry through is predicted. Another way to look at the relative sediment transport capacities is to look at the available energy. In open channel flow with the Tunnel flowing full the flow will be 1587 cfs with a velocity of 9.66 fps and a velocity head of 1.45 ft. In comparison at 85 cfs the velocity is 0.52 fps with a velocity head of 0.004 ft and at 195 cfs the velocity of 1.19 fps has a head of 0.022 ft. The velocity head is a measure of the specific kinetic energy which is available to cause sediment movement. Actual open channel flow would have an energy availability at least 66 times greater per unit volume of water. Multiply in the greater flow and the energy flux in the Tunnel during full open channel flow would be at over 500 times greater than with the Tunnel filled, with the peak through flows noted. This is why sediment transport equations that are based on open channel flow are so far off in this case.

Actually using the ratio of energy fluxes as a correction factor to the sediment load per second predicted by the Yang equation reduces the load from hundreds of pounds per second to one or two pounds a second. Note that this is an oversimplification, but it shows the effect of the assumptions upon which the equations are based.

There will be carry through of suspended solids at peak flows. Efficiency of this Tunnel as a settling tank will be lowered. However, resuspension of settled solids appears unlikely. This is not an open channel situation so many sediment transport equations are not valid. Those that avoid direct use of open channel assumptions have low or zero predicted sediment transport rates.

6.3 Flow Characteristics

Tanks in which treatment is carried out are commonly called reactors. The types of reactors include: batch reactor, plug flow reactor, continuous flow stirred tank reactor, (complete mix), arbitrary flow reactor, packed bed reactor, and fluidized bed reactor. Descriptions of each can be found in texts such as Metcalf and Eddy.

In practice the ideal theoretical plug flow reactor is approximated by a very long rectangular tank. Fluid particles pass through the tank and are discharged in the same sequence in which they enter. The particles retain their identity and remain in the tank for a time equal to the theoretical detention time. This type of flow is approximated in long tanks with a high length to width ratio in which longitudinal dispersion is minimal or absent. The Mercer Street Tunnel meets this ideal description well, during the period when flows are entering at the east end and flowing to the west. This means that the flow in the Tunnel can be represented by a series of pieces of flow, marching in order down the Tunnel. Mixing of the flow inside the Tunnel will be limited. Those pieces of flow will "fall" out the bottom end of the Tunnel in the same order they entered the Tunnel, and they will consist of the same contents as when they entered the Tunnel, minus whatever flow has stuck to the bottom of the Tunnel.

A continuous flow stirred tank, or complete mix reactor, occurs when the particles entering the tank are dispersed immediately throughout the tank. The particles leave the tank in proportion to their statistical population. Complete mixing can be accomplished in round or square tanks if the contents of the tank are uniformly and continuously redistributed. The Wetwell will approximately meet the description of a complete mix tank during peak flow conditions, when flows enter the Wetwell from both directions and are discharged from multiple pump suctions. Complete mixing of the flows entering the Wetwell will occur.

Flow characteristics of the Pump Discharge Channel will also be completely mixed. The high velocity discharges and relatively low volumes will keep that channel completely mixed with very little sedimentation.

The 84 inch system drain inflow to the Wetwell will be plug flow but has relatively high velocities, meaning little sedimentation can occur.

7.0 Probable Solids Dynamics

Based on the velocities, the settling and flow characteristics, the following description of the probable solids dynamics has been prepared. This follows the solids through a "typical" storm event during which discharges occurs at the Elliott West Outfall. Events during which there is no release to Elliott West Outfall (55% of the events) are not described here because they were not of concern to the County.

7.1 Standby Mode

Before a storm occurs, the facility is in standby mode, with no flows in the conveyance or storage facility.

7.2 Tunnel Storage Mode

During a storm event, wastewater levels in the interceptors will rise, overflowing weirs at the West and East end of the Tunnel, and will begin to fill the Tunnel, beginning the storage mode. The Tunnel has approximately 7.2 million gallons of storage. While the Tunnel is filling, no operation is necessary until the Tunnel is completely filled, and the CSO pumping and Treatment mode is initiated. During 15 events per year, the Tunnel will completely fill during an event. When the Wetwell level indicates the Tunnel is full, the Tunnel will switch to CSO Pumping and Treatment mode.

During Tunnel filling, depending on the inflows and relative velocities, and depending on which interceptors are overflowing, the Tunnel, Wetwell and other facilities will have significant velocities and turbulence. The velocity in the Tunnel is dependent on the flow, and the depth of flow in the Tunnel. As the Tunnel fills, the velocities will be reduced, and settling will begin to occur. Large and heavy particles entering the Tunnel and Wetwell will tend to settle where they enter. As velocities decrease, settling will occur. Since the velocities will decrease in the Wetwell and lower end of the Tunnel first, that is where settling will occur first. Since the inflow quantities are also varying at the same time the depth varies, the velocities will also vary.

Using the geometric mean settling velocity of 0.017 cm./sec and the Tunnel diameter of 14.5 feet, (442 cm.), the mean settling time is 7.22 hours. This is the time the mean particle would take to settle to the bottom from the top. This means that in 7.22 hours 100% of the mean sized particles would settle out. The slower particles would be removed at a percentage less than 100%. According to the hydrographs in the System Hydraulics memo, the Tunnel stores for greater than 40 hours during Design storm 6, and pumping occurs for approximately seven hours during this same event.

The Wetwell will include a sump, where most heavy particles scoured from the 84-inch system drain will fall. The sump will only be emptied by the trash pumps into the EBI following a storm event.

The Wetwell has relatively low velocities, but also does not function as a settling tank due to the extremely high surface area loading and small detention time. The Wetwell will function as a completely mixed reactor, with little solids removal during peak flows.

7.3 CSO Pumping and Treatment Mode

When the Tunnel is completely filled, the lead pumping unit will automatically turn on. The pumping units are all adjustable speed drive units, and will be controlled to a set Wetwell elevation. As many pumps will operate at once as are required to maintain the setpoint elevation.

During this mode, flows will continue to enter the system from any or all inflow points. The Design Storm 6 and November 1978 storm flow hydrographs are shown in the System Hydraulics memo by Brown and Caldwell.

The full Tunnel, Wetwell and system drain will see velocities as shown in Table 3. The velocity in the Tunnel is well below any potential scouring velocity. This means that sediment that has settled to the bottom will not be resuspended. Flocculent type material that is still in suspension will move down the Tunnel as the fluid moves, in plug flow. This means that the inflow to the Wetwell from the east will have had the heavy solids removed. With a velocity at the peak of Design Storm 6 of 0.94 feet per second, very little resuspension will occur.

Solids removals in the Tunnel are described in Section 5.4. Depending on the flow velocity, the removal percentage can be determined using the settling curves from the Monitoring Report. At the peak velocity for the one year storm (Design Storm 6), 37 percent of the solids will be removed from the flows entering the Tunnel from the east.

The system drain sees velocities which raise well above scouring velocities in both Design Storm 6 and the November 1978 storm. Solids coming in from the west will not settle in the system drain.

The Wetwell will have flow entering from two directions. While the flow velocities are low, the distance across the Wetwell is short and the detention time at peak flow (Nov. 78) is less than 2 minutes. The detention time at the peak of Design Storm 6 is 2.5 minutes. The Wetwell will be completely mixed and will not collect solids except the heavy solids carried in from the west. These will reach the sump, for pumping to the EBI during Wetwell cleaning.

7.4 Tunnel Dewatering

When a storm event is over, based on reduced inflow and level in the Wetwell the pumps will be stopped. When capacity is available in the EBI, the Operators can approve the station switching to Tunnel Dewatering Mode. In this mode, the sluice gate within the wetwell will close, isolating the wetwell and Tunnel from the EBI. The pump discharge sluice gate will be opened, and one pump will operate, transferring flow into the Pump Discharge Channel, to return to the EBI. Generally, only one pump will operate during Tunnel dewatering, depending on the levels in the EBI at the Denny Regulator and the EBI Control Structure.

When the entire Tunnel and a portion of the Wetwell are dewatered, the main pumping units will be shut off. Final dewatering of the wetwell will be complete with self-priming dewatering pumps. This last flow from the Wetwell will be piped directly to the EBI through a force main. During this pumping, the Wetwell gate will be opened to drain the system drain, and the pump discharge gate will be closed.

Solids from the Wetwell and Tunnel will be pumped to the Pump Discharge Channel and discharge back to the system drain. During this condition, the velocity in the system drain will be 0.8 feet per second. This is less than scouring velocity. The velocity in the Pump Discharge Channel and the effluent pipe to the drop structure will exceed scouring velocities. The 48 inch pipe will have a velocity of 2.5 feet per second.

Solids from the Tunnel cleaning, any Wetwell cleaning, and cleaning of the system drain will flow to the Wetwell. The last 10 feet of the Wetwell will be pumped using the trash pumps, which will discharge straight to the EBI.

The Tunnel will drawdown over a period of approximately 8 hours. As the Tunnel is drawn down, the area of flow changes, increasing the velocity of flow in the Tunnel. The cunette in the bottom of the Tunnel allows less flow to achieve higher velocities. This means that as the Tunnel drains a higher velocity will be achieved.

7.5 Tunnel Cleaning

Upstream of the Tunnel, in the East Portal, a wall and gate are being placed to provide storage for water for Tunnel cleaning. This flush water, combined with the cleaning achieved by the cunette channel during dewatering, will allow solids to be removed from the Tunnel. These solids will flow to the Wetwell for transfer to the EBI. They will receive treatment at West Point.